

Fusion-Enabled Pluto Orbiter and Lander

Completed Technology Project (2016 - 2017)

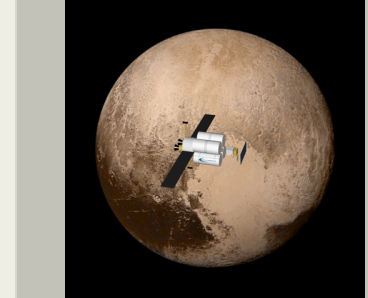


Project Introduction

The Direct Fusion Drive (DFD) concept provides game-changing propulsion and power capabilities that would revolutionize interplanetary travel. DFD is based on the Princeton Field-Reversed Configuration (PFRC) fusion reactor under development at the Princeton Plasma Physics Laboratory. The mission context we are proposing is delivery of a Pluto orbiter with a lander. DFD provides high thrust to allow for reasonable transit times to Pluto while delivering substantial mass to orbit: 1000 kg delivered in 4 years. Since DFD provides power as well as propulsion in one integrated device, it will also provide as much as 1 MW of power to the payloads upon arrival. This enables high-bandwidth communication, powering of the lander from orbit, and radically expanded options for instrument design. The data acquired by New Horizons' recent Pluto flyby is just a tiny fraction of the scientific data that could be generated from an orbiter and lander. Engine modeling accomplished during Phase I has shown that we can expect 2.5 to 5 N of thrust per megawatt of fusion power, with an Isp of about 10,000 seconds and 200 kW available as electrical power. We have evaluated the components of the Pluto trajectory including an Earth departure spiral, constant thrust planar transfer, and Pluto insertion using these thrust and Isp levels, and confirmed the plausibility of the proposed mission. In fact, the mission can depart from LEO with about the mass we originally estimated for an interplanetary insertion, widening the range of available launch vehicles and reducing the cost.##The key objective of the Phase II proposal is to further advance the design and TRL of selected subsystems, such as the superconducting coils, RF heating, and shielding. PPPL will perform experimental work on the existing PFRC-2 testbed using a gas puff valve, to further investigate the dynamics of the thrust augmentation system (additional gas flowing through the FRC scrape-off layer). We will explore the design of a no-thrust mode that captures and reuses the propellant, possibly extracting more power while in orbit around Pluto. Finally, we will develop a model of the synchrotron radiation that is specific to the FRC configuration, as available models are derived from tokamaks. Direct Fusion Drive is a unique fusion engine concept with a physically feasible approach that would dramatically increase the capability of outer planet missions. The fusion-enabled Pluto mission proposed here is credible, exciting, and the benefits to this and all outer planet missions are difficult to overstate. The truly game-changing levels of thrust and power in a modestly sized package could integrate with our current launch infrastructure while radically expanding the science capability of these missions.

Anticipated Benefits

The Direct Fusion Drive (DFD) concept provides game-changing propulsion and power capabilities that would revolutionize interplanetary travel.



A DFD-powered spacecraft in orbit around Pluto, with the lander ready to deploy from the right-hand side. The large wing-like structures are the radiators and the optical communications lasers are on trusses extending from the center. Credits:...

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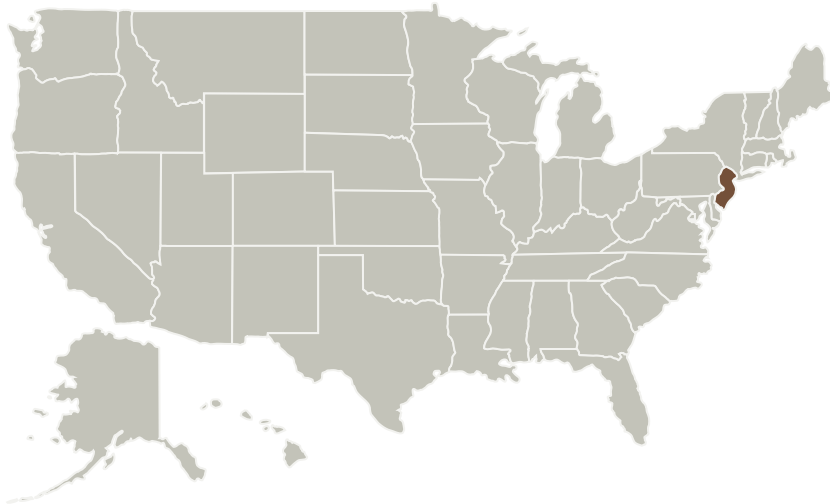
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Primary U.S. Work Locations and Key Partners




| Organizations Performing Work | Role | Type | Location |
|-------------------------------|-------------------|----------|------------------------|
| Princeton Satellite Systems | Lead Organization | Industry | Plainsboro, New Jersey |

Primary U.S. Work Locations

New Jersey

Project Transitions

 **July 2016:** Project Start

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Organization:

Princeton Satellite Systems

Responsible Program:

NASA Innovative Advanced Concepts

Project Management

Program Director:

Jason E Derleth

Program Manager:

Eric A Eberly

Principal Investigator:

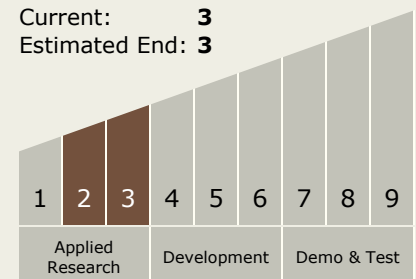
Stephanie Thomas

Technology Maturity (TRL)

Start: 2

Current: 3

Estimated End: 3



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**June 2017:** Closed out

Closeout Summary: The Pluto orbiter mission proposed here is credible and exciting. The benefits to this and all outer-planet and interstellar-probe missions are difficult to overstate. The enabling technology, Direct Fusion Drive, is a unique fusion engine concept based on the Princeton Field-Reversed Configuration (PFRC) fusion reactor under development at the Princeton Plasma Physics Laboratory. The truly game-changing levels of thrust and power in a modestly sized package could integrate with our current launch infrastructure while radically expanding the science capability of these missions. During this Phase I effort, we made great strides in modeling the engine efficiency, thrust, and specific impulse and analyzing feasible trajectories. Based on 2D fluid modeling of the fusion reactor's outer stratum, its scrape-off-layer (SOL), we estimate achieving 2.5 to 5 N of thrust for each megawatt of fusion power, reaching a specific impulse, I_{sp} , of about 10,000 s. Supporting this model are particle-in-cell calculations of energy transfer from the fusion products to the SOL electrons. Subsequently, this energy is transferred to the ions as they expand through the magnetic nozzle and beyond. Our point solution for the Pluto mission now delivers 1000 kg of payload to Pluto orbit in 3.75 years using 7.5 N constant thrust. This could potentially be achieved with a single 1 MW engine. The departure spiral from Earth orbit and insertion spiral to Pluto orbit require only a small portion of the total delta-V. Departing from low Earth orbit reduces mission cost while increasing available mission mass. The payload includes a lander, which utilizes a standard green propellant engine for the landing sequence. The lander has about 4 square meters of solar panels mounted on a gimbal that allows it to track the orbiter, which beams 30 to 50 kW of power using a 1080 nm laser. Optical communication provides dramatically high data rates back to Earth. Our mass modeling investigations revealed that if current high-temperature superconductors are utilized at liquid nitrogen temperatures, they drive the mass of the engine, partly because of the shielding required to maintain their critical temperature. Second generation materials are thinner but the superconductor is a very thin layer deposited on a substrate with additional layers of metallic cladding. Tremendous research is being performed on a variety of these superconducting materials, and new irradiation data is now available. This raises the possibility of operating near-future high-temperature superconductors at a moderately low temperature to dramatically reduce the amount of shielding required. At the same time, a first generation space engine may require low-temperature superconductors, which are higher TRL and have been designed for space coils before (AMS-02 experiment for the ISS). We performed detailed analysis of the startup system and thermal conversion system components. The ideal working fluid was determined to be a blend of Helium and xenon. No significant problems were identified with these subsystems. For the RF system, we conceived of a new, more efficient design using state-of-the-art switch amplifiers, which have the potential for 100% efficiency. This report presents details of our engine and trajectory analyses, mass modeling efforts, and updated vehicle designs.

Closeout Link: <https://www.nasa.gov/feature/fusion-enabled-pluto-orbiter-and-lander>

Technology Areas

Primary:

- TX01 Propulsion Systems
 - └ TX01.4 Advanced Propulsion
 - └ TX01.4.4 Other Advanced Propulsion Approaches

Target Destination

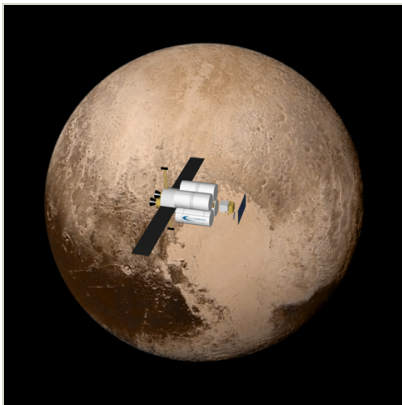
Others Inside the Solar System

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Images



Project Image

A DFD-powered spacecraft in orbit around Pluto, with the lander ready to deploy from the right-hand side. The large wing-like structures are the radiators and the optical communications lasers are on trusses extending from the center.
Credits: Princeton Satellite Systems, NASA/JHUAPL/SwRI
(<https://techport.nasa.gov/image/102325>)

Links

NASA.gov Feature Article
(<https://www.nasa.gov/feature/fusion-enabled-pluto-orbiter-and-lander>)

Project Website:

<https://www.nasa.gov/directorates/spacetech/niac/index.html#.VQb6I0jJzyE>